

*AN EPIDEMIOLOGIC STUDY OF THE ASSOCIATION
BETWEEN PATTERNS OF PHYSICAL TRAINING
AND MUSCULOSKELETAL INJURIES*

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MUSCULOSKELETAL INJURIES

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ABSTRACT

This study identified rates of diagnosis-specific musculoskeletal injuries in United States Marine Corps (USMC) recruits, and examined the association between patterns of physical training and these injuries. Subjects were 1,296 randomly selected USMC male recruits, ages 17 to 28 years, who reported to Marine Corps Recruit Depot (MCRD) San Diego for boot camp training between January 12 and September 14, 1993. Recruits were followed prospectively through 12 weeks of training for injury outcomes. Weekly volumes and types of vigorous physical training were correlated with injury patterns. The overall injury rate was 39.6%, with 82% of injuries occurring in the lower extremities. Overuse injuries accounted for 78% of the diagnoses. The most frequent site of injury was the ankle/foot region (34.3% of injuries), followed by the knee (28.1%). Ankle sprains (6.2%, n = 1,143), iliotibial band syndrome (5.3%, n = 1,143), and stress fractures (4.0%, n = 1,296) were the most common diagnoses. The highest rates of injury were reported during the first 3 weeks of training and during weeks 8, 10, and 11. These weeks included high total volumes of vigorous physical training and the greatest number of hours of running and military marching.

INTRODUCTION

Musculoskeletal injuries are a leading cause of patient morbidity, lost training time, and reduced operational readiness in U.S. military forces.^{7,11,13,15,19,21,22,28,35,37} These injuries are a significant problem in military recruit populations where individuals are exposed to sudden increases in the volume and intensity of physical training. Although many exercise-related musculoskeletal injuries may be preventable, few studies have determined the precise diagnoses and specific etiologies of these costly problems. The development of effective preventive strategies will require the systematic quantification of diagnosis-specific injuries and the investigation of potential risk factors, such as personal characteristics, equipment, and patterns of physical training.

Most of the epidemiological studies of musculoskeletal injuries in military trainees have documented the cumulative incidence of broad categories of injury diagnoses.^{9,13,15,16,19,21,22,28} Rates of specific injuries have been reported only for a few of the most commonly occurring.^{8,15,19,21,22,28,30,33,36} A more precise characterization of injury patterns would provide a better understanding of specific etiologies and risk factors.

Investigations of predictors of exercise-related injuries in military populations have identified primarily intrinsic risk factors, such as baseline fitness levels and prior exercise behavior.^{13,15,19,28,36} Only a few studies have examined the association between physical training and injuries.^{15,16,30,33} These

studies, along with research in civilian runners^{2,3,12,17,23,25,26,31,40} have provided evidence that patterns of physical training are associated with injury occurrence. Since most physical training variables are modifiable, the identification of specific injury risk factors, such as volume, intensity, type, and rates of progression, would provide a framework for the development of cost-effective and feasible preventive strategies.

This investigation was the third in a series of epidemiological studies conducted in USMC recruits by the Naval Health Research Center's Sports Medicine and Research Team (SMART). SMART is a multi-disciplinary group established to design and test interventions for the prevention of musculoskeletal injuries in various military populations. The first two SMART studies performed in USMC recruits at MCRD San Diego identified a high cumulative incidence of podiatric injuries (9.0 per 100 recruit-months)²¹ and of overall orthopedic/soft tissue injuries (19.9 per 100 recruit-months)²² during 12 weeks of boot camp training. The purposes of this third study were to (a) determine diagnostically precise rates of training-related injuries and (b) investigate the role of physical training as an etiologic factor.

METHODS

Subjects

Subjects were 1,347 randomly selected USMC male recruits who arrived at MCRD San Diego for boot camp training between January

12 and September 14, 1993. A roster of recruits reporting for training was obtained weekly, and a sample of study subjects was selected using a table of random numbers. Of the 1,347 recruits selected, 1,296 (96.2%) agreed to participate. After providing informed consent, volunteers were followed prospectively through 12 weeks of recruit training.

Of the 1,296 subjects, 153 (11.8%) separated from USMC service prior to completing boot camp training. Since medical records of discharged recruits were not available for injury outcome determination, all injury rate calculations, with the exception of that of stress fractures, included only boot camp graduates ($n = 1,143$). Recruits discharged due to a stress fracture were identified through review of USMC administrative records so that stress fracture incidence could be determined for the entire sample ($n = 1,296$). The additional surveillance mechanism was conducted for stress fracture occurrence due to the costliness of this injury in terms of patient morbidity and recruit attrition.

Physical Training

USMC recruit training consisted of 12 weeks of standardized military instruction divided into 3 distinct phases: (1) First Phase, weeks 1 through 3, included close order drill/marching, general physical conditioning, and classroom instruction; (2) Second Phase, weeks 4 through 7, consisted of weapons firing and field combat skills training; (3) Third Phase, weeks 8 through 12, included water survival training and a continuation of the

military marching, general physical conditioning, and classroom instruction that began during First Phase.

Hours of scheduled vigorous physical training were quantified by training week and type. Quantification was conducted through review of the USMC recruit training schedule and interviews with USMC training officers. Vigorous physical training was defined as activity requiring an estimated energy expenditure of 6 METS or more.^{20,29} Energy costs were estimated using a published activity classification system.¹

The type of physical training was categorized into 4 major groups: (1) close order drill/marching, (2) general conditioning, (3) military-specific training, and (4) water survival. General physical conditioning included running, calisthenics, obstacle courses, and circuit courses. Military-specific training consisted of mission-related evolutions, such as rappelling, field movement exercises, and 5 to 10-mile load-bearing conditioning hikes.

Injury Data

All injured recruits were treated in the military medical clinics located at the training sites; and all clinic visits were documented in the recruits' individual medical records. Injury outcomes were determined by reviewing each subject's medical record at the completion of his boot camp training. Data collected included date and training day of clinic visit, anatomic site of injury, final diagnosis, associated training events, and whether the symptoms were of acute or insidious

onset.

A musculoskeletal injury was defined as any problem involving bones, muscles, tendons, ligaments, and associated connective tissues for which a recruit presented to the medical clinic. Injuries to the skin and subcutaneous tissues, such as abrasions, blisters, and cellulitis, were not included in the analyses. Musculoskeletal injuries were classified as either acute or overuse. Acute injuries were defined as those precipitated by a sudden forceful traumatic event. Overuse injuries were defined as problems of the musculoskeletal system of insidious onset that were associated with repetitive physical activities.

Diagnostic criteria for stress fractures included: (1) a clinical presentation of localized bone pain, without prior acute trauma, aggravated by activity and relieved with rest; and (2) a confirmatory radiograph and/or triple-phase bone scan. A positive radiograph was defined as the presence of periosteal new bone formation, sclerotic bands, and/or a fracture line in otherwise normal bone.¹⁰ A positive bone scan was defined as the presence of 3+ to 4+ intensity round or fusiform focal uptake²⁷ at an anatomical site consistent with the clinical presentation.

Analysis of Data

Injury data were expressed as: (1) distribution of injuries by anatomic site, (2) cumulative incidence of diagnosis-specific injuries per 100 recruits for the entire 12-week training cycle, (3) incidence of acute and overuse injuries per 100 recruits by

training week, and (4) incidence of injuries per 100 recruit-hours of vigorous physical training by training week. Multiple musculoskeletal diagnoses made in one individual during the same clinic visit were considered discrete injury outcomes. The weekly injury rates reflect the training week that the recruits reported to a medical facility with injury symptoms.

RESULTS

Subjects

All subjects were USMC male enlisted recruits. Ages ranged from 17 to 28 years, with a mean of 19.1 years and a standard deviation of ± 1.7 years. Subjects were predominantly Caucasian (69.7%), with 19.5% Hispanic, 6.0% Black, and 4.8% other.

Physical Training

Figure 1 presents total hours of vigorous physical training by week of boot camp. Table 1 shows training hours categorized by type. With the exception of water survival training, vigorous physical training consisted predominantly of lower extremity weight-bearing activities. Weeks 1, 2, 3, 6, 7, 8, 10, and 11 all included over 14 hours of vigorous weight-bearing exercise. For weeks 6 and 7, most (86.3%) of the vigorous weight-bearing physical training consisted of combat field maneuvers and load-bearing hikes. For weeks 1, 2, 3, 8, 10, and 11, military drill/marching and general physical conditioning comprised the majority (84.7%) of the vigorous weight-bearing

training. Recruits performed 10 to 17 hours of drill and general physical conditioning during those weeks. Most of the general physical conditioning hours included running.

Injury Data

Of the 1,143 subjects who successfully completed boot camp, 453 (39.6%) incurred at least 1 musculoskeletal injury during the 12 weeks of training. The lower extremity was the most frequent anatomical site of injury, accounting for 82% of the diagnoses. The majority of the injuries occurred in the ankle/foot region (34.3% of injuries), followed by the knee (28.1%), the leg (13.7%), and the back/neck/trunk (9.9%) (Fig. 2).

The 12-week cumulative incidence rates per 100 recruits of the most common injury diagnoses are shown in Table 2. Overuse injuries comprised 78% of the diagnoses, while acute injuries accounted for only 22%. The only two acute injuries that occurred with any significant frequency were ankle sprains (6.2%, $n = 1,143$) and contusions (3.7%, $n = 1,143$). The most frequent overuse injury, and the second most common overall injury, was iliotibial band syndrome (5.3%, $n = 1,143$). Stress fractures were the second most common overuse injury, with an incidence of 4.0% ($n = 1,296$).

The incidence rates of overuse and acute injuries by training week of recruit presentation to a medical facility are displayed in Figure 3. The distribution patterns were approximately the same for both types of injuries. Injuries were reported most often during the first 3 weeks of training and

during weeks 8, 10, and 11. These weeks were characterized by high total volumes of vigorous physical training and the most hours of running and military marching.

Figure 4 presents the distribution of total injuries per 100 recruit-hours of vigorous physical training by training week. When expressed per recruit-hours of training, the highest injury rates clustered during the earliest weeks of training, with the exception of one late peak during week 10.

DISCUSSION

This study was the first to quantify diagnosis-specific musculoskeletal injuries in USMC recruits and to systematically examine the role of physical training as a potential causal factor. Injuries occurred at a high rate (39.6%), with the majority of diagnoses being overuse injuries of the lower extremities. The weekly distributions of injury rates and hours of vigorous physical training followed similar patterns, indicating that volume of vigorous physical training may be an etiologic factor for exercise-related injuries. Our findings also suggest that rapid rates of exercise progression, abrupt changes in training patterns, and lower extremity weight-bearing types of exercise may further contribute to injury risk.

The overall cumulative incidence (39.6%)^{9,13,15,16,19} and anatomical distribution^{13,15,22} of injuries found in this study are similar to those described in other investigations of military training populations. A higher injury rate (19.9 per 100 recruit-

months, 59.7% for a 12-week training cycle) was reported in the first SMART investigation in USMC recruits.²² However, in that study, the definition of injury included disorders of the skin and subcutaneous tissues, such as blisters and cellulitis. Dermatological problems were excluded from analyses in this study which would account for the lower injury rate.

The study finding of the ankle/foot region as the most frequently injured area is consistent with results reported in the initial SMART investigation in this population.²² A comparative anatomical distribution of training-related injuries has been found in studies of U.S. Army trainees¹⁵ but not in those of some foreign military recruits^{9,16} where the knee has been reported as the primary site of injury. The disparities in injury distribution found between U.S. and other military populations may be due to several factors, such as differences in footwear, training techniques, terrain, and definitions of injuries.

The lack of diagnostic precision in previous studies in similar populations make the direct comparison of rates of specific diagnoses difficult. However, some studies in U.S. military trainees have reported the cumulative incidence of a few of the most common diagnoses.^{15,21,22} Our study results are comparable to these earlier findings. Specific injuries frequently cited as the most commonly occurring include stress fractures, ankle sprains, iliotibial band syndrome, patellar tendinitis, achilles tendinitis, plantar fasciitis, shin splints,

and lower extremity stress syndromes. With the exception of ankle sprains, all of these diagnoses usually are considered overuse injuries. The same injuries also are the most frequently reported in civilian runners,^{3,12,23,26,39} suggesting that the etiologies may be similar.

This was the first study to examine rates of both acute and overuse injuries by training week (Fig. 3). The finding that the distributions followed approximately the same pattern indicates that these injuries may share some common risk factors. From an injury prevention perspective, this finding is important since it suggests that interventions targeting the more common overuse injuries also may effectively reduce the incidence of acute traumatic events.

This was one of the initial studies in military recruits to examine distributions of injuries relative to patterns of physical training. With the exception of weeks 6 and 7, we found that peaks in injury rates occurred during the weeks with the greatest total volume of vigorous physical training (Figs. 1 and 3). These findings are consistent with studies in civilian runners that have reported training volume (weekly running distance) as a significant risk factor for exercise-related injuries.^{2,3,12,17,23,25,26,31,40} In our study, weekly injury rates were based on the day that the recruit presented to the clinic with symptoms of injury. Since the week of presentation may not have corresponded directly to the week of symptom onset, the rates may reflect the cumulative effects of the current as well as prior

weeks' physical training, particularly in the case of overuse injuries. This delay in injury diagnosis might explain the relatively low injury rates seen during weeks 6 and 7, despite the respective high training loads. During those weeks, recruits trained in a fairly remote field environment, and in week 8 they returned to MCRD where they had easy access to the sports medicine clinic.

Although weekly training volume has been most consistently cited as a predictor of exercise-related injuries, some studies have suggested that other training variables, such as type, intensity, frequency, duration, and rates of progression may be contributing factors.^{4,14,24,39} The results of our study support the concept of a multi-factorial effect of physical training. The weeks with the highest injury rates were characterized by the most hours of military drill and general physical conditioning (running). Comparable findings were reported in a similar study of South African Army recruits.¹⁶ Another study in U.S. Army trainees found an association between weekly running volume and injury incidence.¹⁵ Furthermore, the distribution and type of injuries reported in military trainees^{9,13,15,16,19,21,22,35} are similar to those seen in civilian runners.^{3,12,23,26} All of these results indicate that exercise type, particularly repetitive weight-bearing activity, is an important factor to consider in injury causality.

The high injury rates found during the earliest weeks of boot camp may be explained not only by the high volumes of

exercise but by the rapid rate of training progression. Some studies in recreational runners have cited lack of prior running experience^{3,25,26} and "training error"²³ (abrupt increases or changes in training) as risk factors for running-related injuries. The high volume of vigorous physical activity, more than 15 hours per week, conducted during the first 3 weeks of USMC training may have constituted training error for many recruits, particularly the previously sedentary.

When the injury incidence was expressed as a function of hours of exposure to physical training, the highest weekly rates were most consistently seen during the earliest weeks of boot camp (Fig. 4). A similar pattern was reported in the South African Army study.¹⁶ Another investigation in civilian runners showed that as running experience increased, injuries per unit of running exposure declined.³ All of these findings suggest that as individuals become more fit through regular physical activity, they become more resistant to exercise-related injuries. This theory is supported by laboratory evidence that progressive physical conditioning and overload of musculoskeletal tissues stimulates a protective adaptive response.^{5,6,32,34}

The late peak in injuries per hour of training exposure seen in week 10 (Fig. 4) also may be attributable to training error. On the last day of week 9, the recruits returned to a schedule of nearly daily high volume weight-bearing activities following a week of no physical training. The sudden increase in the injury rate in week 10 provides further evidence that abrupt

changes in training patterns may contribute to injury risk.

In this study, hours of scheduled vigorous physical training were used as an estimate of total training volume. Only vigorous training was quantified since nearly all scheduled physical events required an estimated energy expenditure of 6 METS or more. Since training intensity (such as pace of running events) increased slightly through the training cycle, more volume of exercise actually may have been performed per hour later in the schedule. Furthermore, 6 METS may have constituted only moderate intensity activity for relatively fit individuals. Future studies should include a more precise quantification of physical training in terms of volume, frequency, intensity, and duration. Non-scheduled physical activities, such as incidental movement miles from training site to training site, should also be measured to provide a more accurate assessment of total exercise exposure. Since our results indicate that recruits were particularly susceptible to injury during the early phases of training, intrinsic factors, such as baseline fitness levels and prior exercise histories, also should be investigated as contributors to injuries in this population.

The systematic identification of exercise-injury risk factors, through controlled epidemiological studies such as this, will form the basis for the development of effective injury prevention strategies. The civilian community, as well as the military, will benefit from this type of research.

Musculoskeletal injuries are also commonly associated with

routine exercise in non-military populations,^{14,18,24,39} with annual injury rates as high as 65% reported in recreational runners.²³

With the current public health emphasis on the promotion of physical activity,³⁸ there is an increased need for the scientific investigation of strategies that will minimize the risks of exercise-related patient morbidity and healthcare costs.

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Table 1
Hours of vigorous physical activity (≥ 6.0 METS) by training week in male U.S. Marine Corps recruits, MCRD San Diego, January-September 1993.

Week	Drill / Marching	General conditioning	Military	Water survival	Total
1	11.2	5.8	0	0	17.0
2	5.3	4.8	3.9	1.7	15.7
3	3.7	6.3	5.2	0	15.2
4	1.8	4.0	2.3	0	8.1
5	0.8	2.5	3.5	0	6.8
6	0	1.0	16.5	0	17.5
7	1.8	1.8	12.5	0	16.1
8	7.7	6.5	0	7.2	21.4
9	2.7	1.8	0	0	4.5
10	8.0	6.8	1.0	0	15.8
11	6.3	5.5	4.0	0	15.8
12	0.8	0.8	0	0	1.6
Total	50.1 (32.2%)	47.6 (30.6%)	48.9 (31.5%)	8.9 (5.7%)	155.5 (100%)

Table 2
Incidence rates of most common musculoskeletal injury
diagnoses in male U.S. Marine Corps recruits (n=1143),
MCRD San Diego, January - September 1993

Disorder	No. of cases	Incidence
Ankle sprains	71	6.2%
Iliotibial band syndrome	61	5.3%
Stress fractures*	52	4.0%
Contusions	42	3.7%
Low back pain	33	2.9%
Foot pain	32	2.8%
Patellar tendinitis	28	2.4%
Shin splints	21	1.8%
Gastrocnemius strain	16	1.4%
Stress reaction/periostitis	14	1.2%
Hamstring strain	13	1.1%
Patellofemoral syndrome	12	1.0%
Achilles tendinitis	10	0.8%
Non-specific ankle pain	8	0.7%
Non-specific knee pain	8	0.7%
Knee sprain/strain	8	0.7%
Unspecified ankle/foot tendinitis	8	0.7%
Ankle capsulitis	8	0.7%
Hip flexor strain	6	0.5%
Non-specific leg pain	6	0.5%
Trapezius strain	5	0.4%
Plantar fasciitis	4	0.3%
Wrist sprain/strain	4	0.3%
Deltoid strain	4	0.3%
Rhomboid strain	4	0.3%
Knee tendinitis/bursitis	4	0.3%

* n = 1,296

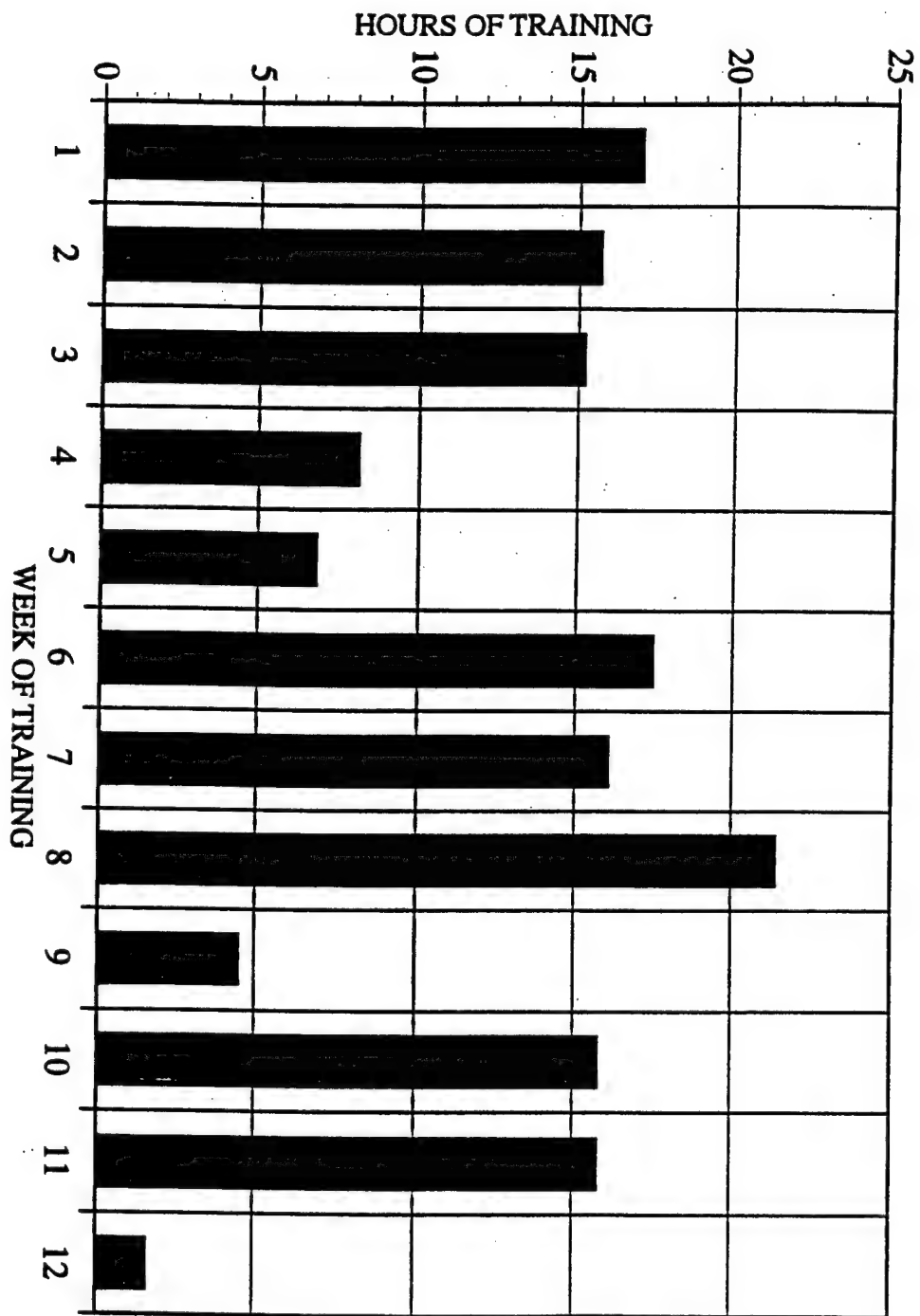


Figure 1. Hours of vigorous physical activity (≥ 6.0 METS) by training week in male U.S. Marine Corps recruits, MCRD San Diego, January -September 1993.

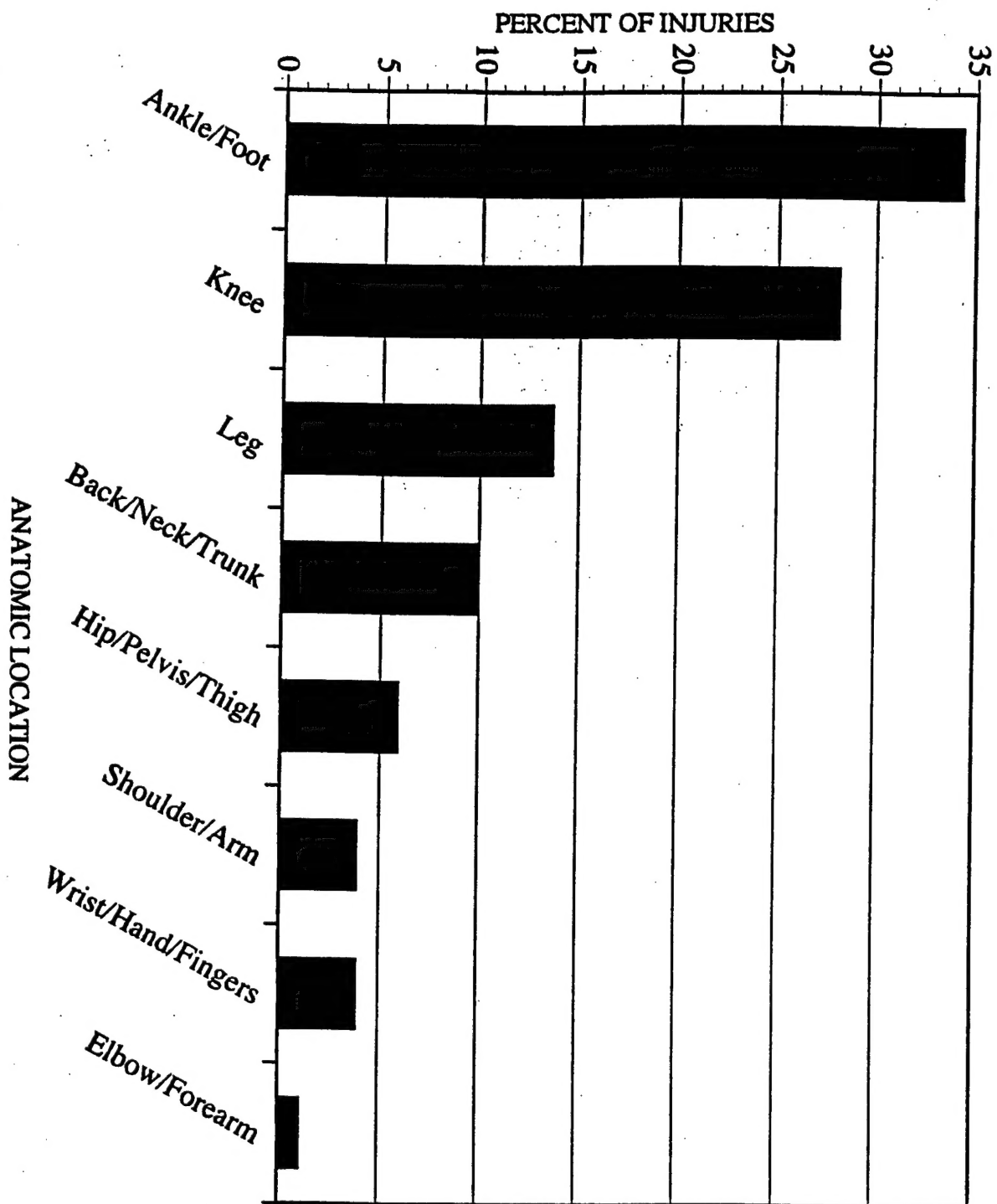


Figure 2. Distribution of musculoskeletal injuries by anatomic location in male U.S. Marine Corps recruits, MCRD San Diego, January - September 1993.

INCIDENCE RATE PER 100 RECRUITS

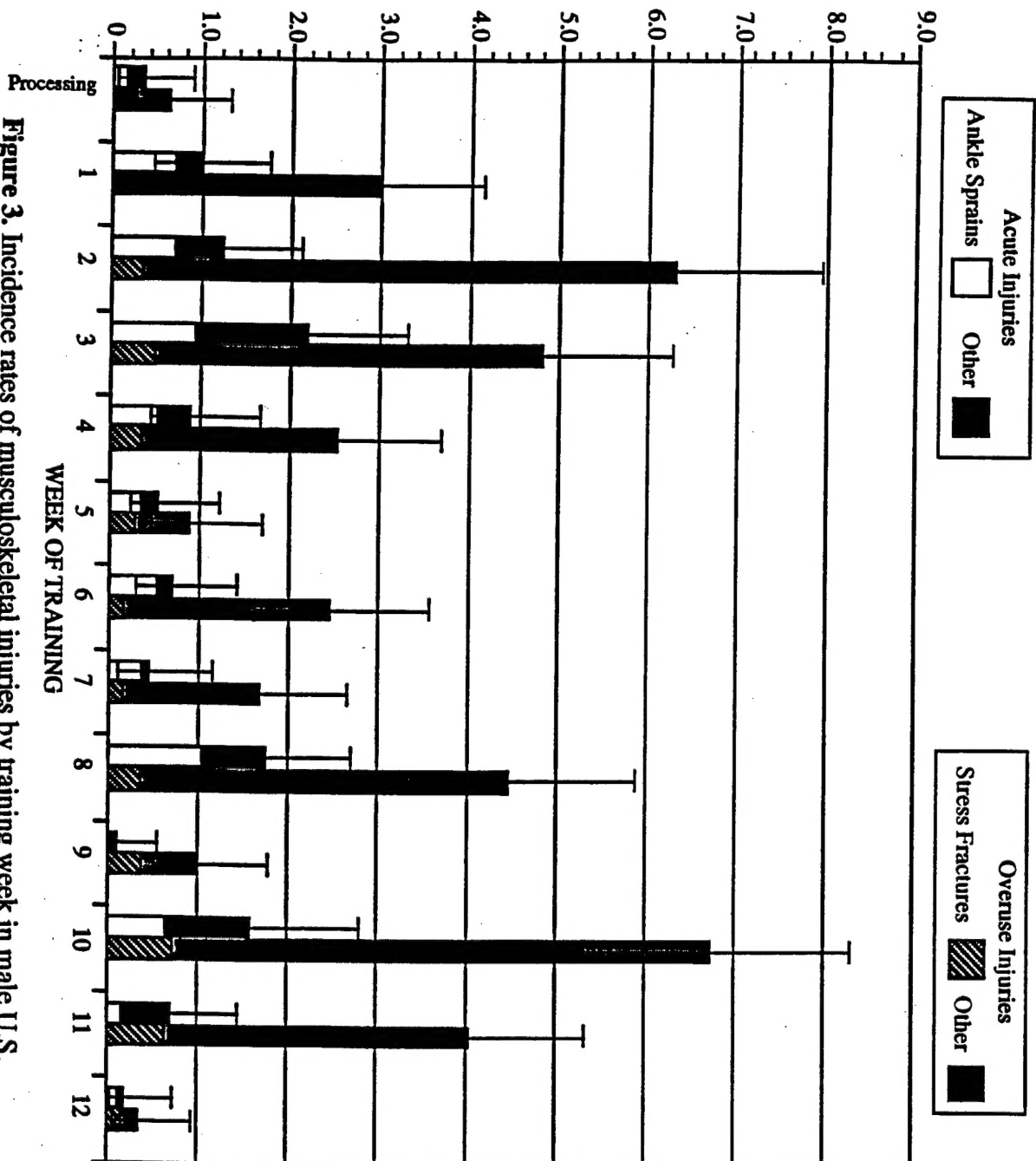


Figure 3. Incidence rates of musculoskeletal injuries by training week in male U.S. Marine Corps recruits, MCRD San Diego, January - September 1993 (with 95% confidence intervals).

INCIDENCE RATE OF INJURIES
(PER 100 RECRUIT-HOURS OF VIGOROUS PHYSICAL TRAINING)

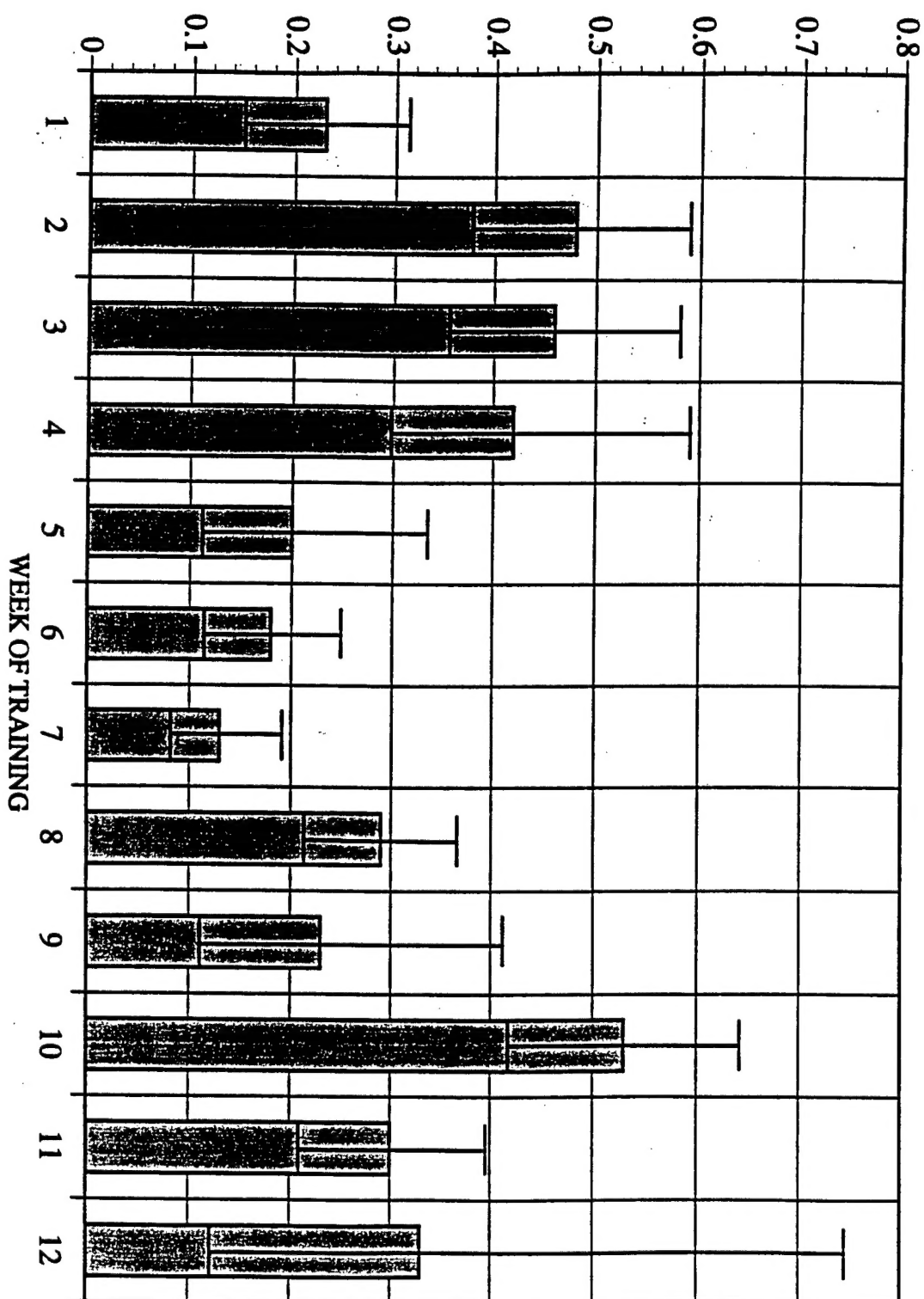


Figure 4. Incidence rate of musculoskeletal injuries per 100 recruit-hours of vigorous physical training by week of training in male U.S. Marine Corps recruits, MCRD San Diego, January - September 1993 (with 95% confidence intervals).

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13. ABSTRACT (Maximum 200 words)

This study identified rates of diagnosis-specific musculoskeletal injuries in United States Marine Corps (USMC) recruits, and examined the association between patterns of physical training and these injuries. Subjects were 1,296 randomly selected USMC male recruits, ages 17 to 28 years, who reported to Marine Corps Recruit Depot (MCRD) San Diego for boot camp training between January 12 and September 14, 1993. Recruits were followed prospectively through 12 weeks of training for injury outcomes. Weekly volumes and types of vigorous physical training were correlated with injury patterns. The overall injury rate was 39.6%, with 82% of injuries occurring in the lower extremities. Overuse injuries accounted for 78% of the diagnoses. The most frequent site of injury was the ankle/foot region (34.3% injuries), followed by the knee (28.1%). Ankle sprains (6.2%, n = 1,143), iliotibial band syndrome (5.3%, n = 1,143), and stress fractures (4.0%, n = 1,296) were the most common diagnoses. The highest rates of injury were reported during the first 3 weeks of training and during weeks 8, 10, and 11. These weeks included high total volumes of vigorous physical training and the greatest number of hours of running and military marching.

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